

**Design and implementation of an FPGA-based timing pulse  
programmer for pulsed-electron paramagnetic resonance applications**

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# SUPPORTING INFORMATION

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## Pulsed-EPR Spectrometer: Detailed Description

The basic operational features of the home designed and constructed pulsed-EPR spectrometer are described in the article. A simplified block diagram of the pulsed-EPR spectrometer and associated devices is presented in Figure S1. The “A” arm in Figure S1 includes a PIN diode switch and 0/180°, biphasic modulator, and a continuously variable phase shifter and a variable attenuator, for manual adjustment of the MW phase and power. The “B” arm in Figure S1 includes a PIN diode switch, followed by the combination of a 90° hybrid coupler, parallel biphasic modulators, and combiner. This block allows microwave phase alternations of 0, 90, 180 and 270°. The components support broadband operation over the frequency range, 8.2-18.0 GHz, which covers the X-band and Ku-band (or P-band) ranges. Coaxial components have a minimum bandwidth of 8-18 GHz, and are connected by using RG402U (0.141 in; represented by thin lines in Figure S1) or RG401U (0.250 in; intermediate thickness lines) semirigid coaxial cable. Two separate waveguide sections (thick lines) use WR-90 (X-band) or WR-62 (Ku-Band) waveguide and components (Paths C, D, in Figure S1).

The selected specifications, model numbers and suppliers of the numbered components in Figure S1, are as follows:

- (1) Microwave synthesizer/sweeper (0.01-20 GHz; power: -15 dBm min., 10 dBm max., leveled), 83752A, Hewlett-Packard (Palo Alto, CA)
- (2) Amplifier (GaAs FET, 40 dB), ALM/180-5040, CTT (Santa Clara, CA)
- (3) Travelling wave tube amplifier [42 dB, 1 kW max., 1.5% duty cycle, rf output rise/fall 15 ns, phase droop correction option; includes interchangeable output isolator: C1-X153141 (X-

- band), C1-P153112 (Ku-band)], 117X/Ku, 54303-1, Applied Systems Engineering (Fort Worth, TX)
- (4) Magnetomer-Field Controller, B-H15, Bruker (Billerica, MA)
  - (5) Magnet power supply (0-85 A at 0-170 VDC, HS1785-455, Walker Scientific (Worcester, MA)
  - (6) Electromagnet (1.2 T at 85 A, max.), HF-12H, Walker Scientific
  - (7) Cryostat, SVT-200, Janis Research Co. (Wilmington, MA)
  - (8) Limiter (PIN diode; threshold, +9 dBm; response/recovery time, 10-20 ns), LP8018, Herotek (San Jose, CA)
  - (9) Amplifier (GaAs FET, 21 dB), ALM/180-5021, CTT (Santa Clara, CA)
  - (10) Band pass filter (2-18 GHz), 3DH1-2000/T18000-00, K&L Microwave (Salisbury, MD)
  - (11) Quadrature mixer, 250270, Anaren Microwave (East Syracuse, NY)
  - (12) Double balanced mixer, 73230, Anaren Microwave
  - (13) Amplifier stage: Encased unit contains the following four amplifiers, on four selectable separate channels: Two bipolar amplifiers (dc-300 MHz; 10×), 6950; two bipolar amplifiers (dc-100 MHz, 100×), 6931; Phillips Scientific (Mahwah, NJ)
  - (14, 15) Amplifier stage: Encased unit contains the following two amplifiers and attenuators, on selectable, separate channels: Amplifier (dc-190 MHz; 20 dB), E220-N-BNC-50-50-25, Comlinear Corporation (Fort Collins, CO); Dual rotary attenuator (0-50 dB), 50DR-003, JFW Industries (Indianapolis, IN)
  - (16) Digital sampling oscilloscope, (500 MHz bandwidth, 2.5 GSa/s, 2 active, 2 passive channels, Advanced Math option), TDS620B, Tektronix (Beaverton, OR)
  - (17) Console computer: PC (current: Optiplex 9010, Dell)

(18) FPGA pulse generator, Spartan-6 LX45, Xilinx (San Jose, CA). For the detailed description of the encased FPGA unit, see full article.

Additional components, that are included in the block diagram in Figure S1, are as follows:

#### Coaxial Components

- Isolator (17 dB, minimum), T708S01, Mica Microwave (Manteca, CA)
- Phase shifter (manual), 9428A, ARRA (Bayshore, NY)
- Attenuator (manual), P9804-20, ARRA
- Switch (SPST, PIN diode; Pulse Forming Network), FM864CH, General Microwave (Farmingdale, NY)
- Switch (SPST, PIN diode; miniature; Receiver), F9114A, General Microwave
- Biphase modulator ( $0/180 \pm 10$  deg), F1938, General Microwave
- Power divider (3 dB), 2089-6209-00, M/A-COM (Lowell, MA)
- Hybrid coupler (3 dB, 90 deg, crossover), 2032-6374-00, M/A-COM
- Directional couplers, 2025-6020-10 (-10 dB), 2025-6020-20 (-20 dB), M/A-COM
- Detectors, 2087-6001-00, M/A-COM; 201B, Krytar (Sunnyvale, CA)
- DC block, 2044-6010-00, M/A-COM

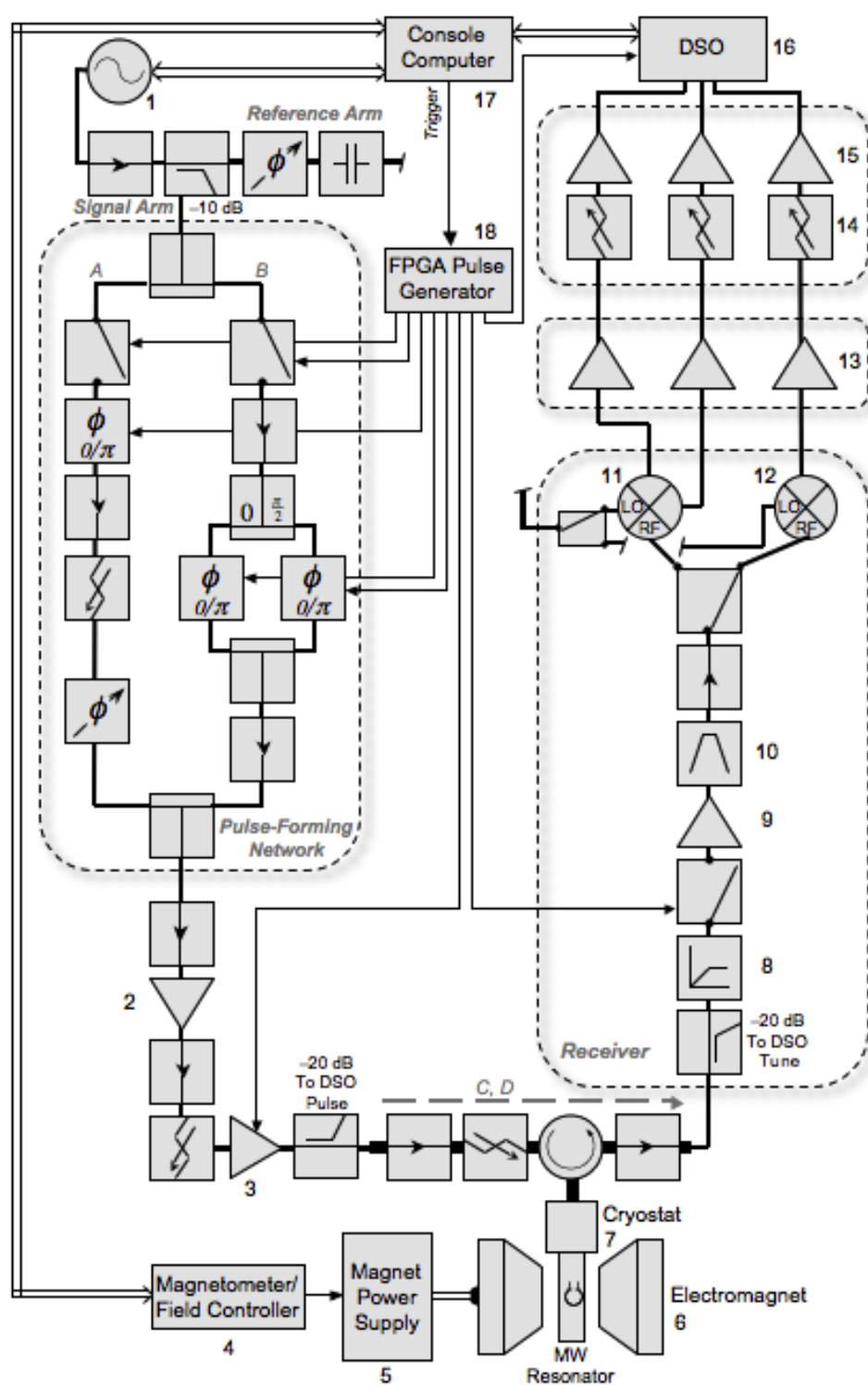
#### Waveguide Components

##### *X-band:*

- isolator, X-band (30 dB), 1203, Polytechnic Research & Development (Brooklyn, NY)
- rotary vane attenuator, X-band (0-50 dB), X382A, Hewlett-Packard
- circulator, X-band (3 port, 1 kW, 20 dB isolation), Microwave Associates (M/A-COM)

*Ku-band:*

- isolator, Ku-band (24 dB), Y157A, Microlab/FXR (Parsippany, NJ)
- rotary vane attenuator, Ku-band (0-50 dB), P382A, Hewlett-Packard
- circulator, Ku-band (3 port, 1 kW, 20 dB isolation), MA-8K220, Microwave Associates (M/A-COM)



**Figure S1.** Simplified block diagram of the pulsed-EPR spectrometer.